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US ARMY ELECTRONICS RESEARCH & DEVELOPMENT ACTIVITY

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NEW MEXICO

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ENVIRONMENTAL SCIENCES DEPARTMENT
U. S. ARMY ELECTRONICS RESEARCH AND DEVELOPMENT ACTIVITY
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ABSTRACT

Turbulent characteristics of the first 62 meters of the atmosphere in the vicinity of the U. S. Army Electronics Research and Development Activity's Meteorological Research Tower are established for neutral conditions. The assumption was made that the roughness length is a constant, but dependent upon wind direction, fetch, and the height of the roughness elements.

Data are presented for five recording periods during the late winter and early spring of 1958 and 1961. Computations of the basic wind profile and turbulence parameters are presented in tabular form.

CONTENTS

INTRODUCTION

The motion of the atmosphere near the surface of the earth is rarely as simple as described by the theory of laminar flow. Normally, flow in the atmosphere consists of a fairly simple mean motion on which is superimposed extremely complicated secondary or eddy motions of oscillatory, but not necessarily periodic, character. The superimposed eddy motion results in the often chaotic wind profile and turbulent spectrum observed in the boundary layer.

Fluctuations about the mean flow in the atmosphere are the function of a number of conditions, including the air-earth interface and the exchange of energy between the atmosphere and the underlying surface. These boundary conditions plus the prevailing lapse rate are the determining factors for variations in the local wind profile. The basis for any study concerning turbulent, or eddy motion in the atmosphere is the establishment of initial boundary conditions. This report is concerned with establishing these basic parameters for the immediate vicinity of the U. S. Army Electronics Research and Development Activity's (USA ERDA) Meteorological Research Tower.

THE METEOROLOGICAL TOWER FACILITY

The meteorological tower facility was established for basic research with respect to wind effects on unguided rockets, including wind profile studies, the spectrum of turbulence, and the prediction of the local wind profile. The tower instrumentation, the surrounding terrain, and the climatology of White Sands Missile Range (WSMR), New Mexico, have been described adequately elsewhere [1, 2].

WIND PROFILE HYPOTHESES

The two hypotheses most commonly used to describe the wind profile in the boundary layer are the power law and the logarithmic law. The power law, better known as the "seventh root law" or Schmidt's conjugate power law, normally takes the form

$$\bar{u} = \bar{u}_1 \left(\frac{z}{z_1}\right)^p$$

where $\bar{u}$ is the mean wind speed at height z,

$\bar{u}_1$ is the mean wind speed at height z_1, and

p is the profile index.

Its use is limited to profiles over surfaces which are either bare or covered with very short vegetation. The profile index p is also dependent upon the vertical temperature gradient.

The logarithmic profile is based upon a steady two-dimensional motion in the proximity of a surface $z = 0$ with $\overline{u}$ as a function of z only. In fully developed turbulent flow, the object is to find a velocity profile $\overline{u}$ (z) which is consistent with a given shear stress and under the assumption that the temperature gradient is near adiabatic. The equation has taken many forms, the most common being attributed to Rossby [3]:

$$\frac{\overline{u}}{u_*} = \frac{1}{k} \ln \left(\frac{z + z_0}{z_0}\right)$$

for a fully rough surface, where

$\overline{u}$ = mean wind speed,

$$u_* = \left(\frac{\tau_0}{\rho}\right)^{\frac{1}{2}} = \text{friction velocity},$$

k = von Karman's constant,

z = height,

z_0 = roughness length.

Utilizing the power and logarithmic laws in the preceding forms, expressions for the boundary layer parameters can be derived.

The Roughness Length: The roughness length, z_0, a constant of integration, is related to the height of the surface irregularities by $z_0 \approx \epsilon/30$. This implies that the mean velocity tends toward zero at a height depending upon the average length of the roughness elements. The roughness length z_0 can be easily determined from the $\overline{u}$, log z plot under adiabatic or neutral lapse conditions.

The Surface Shearing Stress, Friction Velocity, and Drag Coefficient: The Reynolds stresses indicate that fluctuations in velocity cause transport of momentum across a surface in a fluid. In general, the Reynolds stresses outweigh the viscous stresses, which often may be neglected in problems of turbulent motion. The horizontal shearing stress [3] is given by:

$$\tau = \overline{-\rho u'w'}$$

where ρ is mean density and u'w' are mean fluctuating or eddy velocities. The shearing stress is assumed to be independent of height within the first 50-100 meters above the surface, according to Lettau [4], and related to the friction velocity by

$$u_*^2 = \left|\frac{\tau}{\rho}\right| = (|\overline{u'w'}|)^{\frac{1}{2}}$$

and to the surface shearing stress and the coefficient of drag by

$$\tau = \tau_o + z \frac{\partial \overline{P}}{\partial x}$$

$$\tau_o = \frac{1}{2} \rho C_D \overline{u_s^2}$$

where u_s is the wind velocity "near" the surface. Since

$$C_D = \frac{2\tau_o}{\rho \overline{u}^2},$$

it follows that

$$C_D = 2 \left(\frac{u_*}{\overline{u}}\right)^2 = \frac{2k^2}{\left(\ln \frac{z + z_o}{z_o}\right)}$$

assuming the Rossby profile.

The Eddy Viscosity: Sutton [5] states that a basic step in turbulence research is to adopt the fundamental ideas of the kinetic theory of gases by expressing the transfer of momentum or any other suitable entity, by means of virtual coefficients of viscosity, conductivity, and diffusivity, defined in much the same way as their molecular counterparts. These exchange coefficients, expressions for the turbulent flux, may be derived independently of any theory of the structure of eddy motion. The eddy viscosity, or the turbulent transfer of momentum by eddies giving rise to an internal fluid friction, is defined as

$$\frac{\tau}{\rho} = (\nu + K_M) \frac{d\overline{u}}{dz} \approx K_M \frac{d\overline{u}}{dz} \text{ if } \nu \ll K_M$$

$$K_M = \frac{\overline{u'w'}}{\frac{d\overline{u}}{dz}}$$

where K_M is the eddy viscosity. From the above relationship and the Rossby profile, the eddy viscosity can be defined as

$$K_M = k u_* z$$

which leads to a valid approximation for boundary conditions.

DATA ANALYSIS

Wind and temperature profiles originally observed for spectral analysis purposes at the tower site were used to determine boundary conditions and to investigate the application of the profile hypotheses to the basic data The raw data were recorded on five different days, and the length of recording varied from one to six hours. One-hour samples were obtained on 12 February 1958, 13 February 1958, and 7 March 1958, and consisted of wind velocity and temperatures for nine tower levels. Six-hour samples were obtained on 15 and 16 March 1961 for four tower levels. The 1958 data were reduced as five-second visual averages for the wind velocities, with temperatures read every 44 seconds. The 1961 data were reduced as four-second and sixty-second averages for the winds and temperatures, respectively.

All data were punched on Hollerith cards for machine analysis. Wind and temperature profiles by the hour and by ten-minute intervals were then computed using the Philco 2000 computer. The fifteen hourly means and deviations are presented in Tables I to V. The 90 ten-minute mean profiles were used to establish boundary conditions for the tower data (Tables VI to X).

BOUNDARY CONDITIONS

To establish the basic turbulence parameters for the tower area, the wind and temperature profiles were inspected for adiabatic or neutral conditions. Of the 90 profiles available, 11 were found that met the criteria. The 11 wind profiles were plotted (Figures 1-11) on semi-logarithmic paper, and the line of regression determined by a least squares fit. The $\overline{U}$, log z intercept was taken as the roughness length z_0 The equivalent surface roughness vs wind speed at 4 3 and 4.6 meters is shown in Figure 12.

The average height of the roughness elements surrounding the tower facility is approximately three meters, giving a theoretical z_0 of ten centimeters, which is in close agreement with the observed data and with the results of other experimenters in the field.

Assuming the roughness length to be valid for the tower area, values of z_0 picked from the curve (Figure 12) were used to compute the friction velocities for each ten minute profile. The remainder of the boundary parameters under discussion were also computed at this time and are presented in Tables XI through XV. All calculations were for a height range of 4 3 to 4.6 meters above the surface and a fetch* of 40 to 70 meters

DISCUSSION

A careful examination of the boundary parameters indicates a dependence on the mean wind speed; however, in the case of the coefficient of drag, C_D, it is apparent that the wind direction has a decided effect. The larger values of C_D (0.029 to 0.032) tend to occur when the mean wind direction is from the quadrant in which the largest roughness elements are with respect to the tower (Figure 13)

*Fetch is defined as the upwind distance from nearest obstruction to the instrumentation

TABLE I

WIND AND TEMPERATURE DATA FOR 1001-1100 MST, 12 FEBRUARY 1958

z Height (meters)	$\bar{u}$ Wind Speed (m sec^{-1})	$\sigma_{\bar{u}}$ Standard Deviation (m sec^{-1})	$\bar{A}$ Wind Direction (degrees)	$\sigma_{\bar{A}}$ Standard Deviation (degrees)	$\bar{T}$ Temperature (degrees C)	$\sigma_{\bar{T}}$ Standard Deviation (degrees C)	I Gustiness Ratio
4.6	3.7	0.83	179	14.2	4.2	0.56	0.22
11.9	4.6	0.89	177	14.0	3.7	0.57	0.19
19.3	-.7	0.87	174	12.7	3.5	0.53	0.18
26.6	5.0	0.84	177	12.7	3.2	0.49	0.17
33.9	5.1	0.78	178	11.2	3.2	0.49	0.15
41.2	5.2	0.74	178	11.4	3.2	0.49	0.14
48.5	5.1	0.72	178	11.2	2.9	0.48	0.14
55.8	5.0	0.68	178	10.2	2.9	0.52	0.13
62.0	5.3	0.66	175	6.4	2.8	0.51	0.12

TABLE II

WIND AND TEMPERATURE DATA FOR 1202-1301 MST, 13 FEBRUARY 1958

z Height (meters)	$\bar{u}$ Wind Speed (m sec^{-1})	$\sigma_{\bar{u}}$ Standard Deviation (m sec^{-1})	$\bar{A}$ Wind Direction (degrees)	$\sigma_{\bar{A}}$ Standard Deviation (degrees)	$\bar{T}$ Temperature (degrees C)	$\sigma_{\bar{T}}$ Standard Deviation (degrees C)	I Gustiness Ratio
4.6	5.5	1.85	257	22.5	12.8	0.75	0.33
11.9	6.9	2.29	245	20.8	12.2	0.56	0.33
19.5	7.6	2.51	241	22.0	12.5	0.56	0.33
26.6	7.9	2.56	242	21.8	11.8	0.48	0.32
33.9	8.2	2.65	245	22.3	11.9	0.45	0.32
41.2	8.5	2.74	246	21.8	11.9	0.41	0.32
48.5	8.7	2.78	246	20.4	11.9	0.44	0.32
55.8	8.8	2.75	246	21.0	11.7	0.36	0.31
62.0	9.1	2.85	248	20.3	11.6	0.32	0.31

TABLE III

WIND AND TEMPERATURE DATA FOR 1334-1433 MST, 7 MARCH 1958

z Height (meters)	$\bar{u}$ Wind Speed (m sec^{-1})	$\sigma_{\bar{u}}$ Standard Deviation (m sec^{-1})	$\bar{A}$ Wind Direction (degrees)	$\sigma_{\bar{A}}$ Standard Deviation (degrees)	$\bar{T}$ Temperature (degrees C)	$\sigma_{\bar{T}}$ Standard Deviation (degrees C)	I Gustiness Ratio
4.6	8.7	1.81	283	5.1	4.8	0.46	0.21
11.9	11.0	2.07	282	6.1	4.8	0.47	0.19
19.3	12.6	2.15	280	6.7	4.6	0.44	0.17
26.6	13.4	2.03	280	5.5	4.4	0.67	0.15
33.9	14.0	2.08	282	5.7	4.3	0.48	0.15
41.2	14.5	2.20	284	5.4	4.3	0.46	0.15
48.5	15.1	2.22	281	4.8	4.3	0.45	0.15
55.8	15.4	2.21	281	4.9	4.3	0.45	0.14
62.0	15.9	2.24	283	4.6	4.2	0.43	0.14

TABLE IV

WIND AND TEMPERATURE DATA FOR 1001-1600 MST BY THE HOUR, 15 MARCH 1961

z Height (meters)	$\bar{u}$ Wind Speed ($m\ sec^{-1}$)	$\sigma_{\bar{u}}$ Standard Deviation ($m\ sec^{-1}$)	$\bar{A}$ Wind Direction (degrees)	$\sigma_{\bar{A}}$ Standard Deviation (degrees)	$\bar{T}$ Temperature (degrees C)	$\sigma_{\bar{T}}$ Standard Deviation (degrees C)	I Gustiness Ratio
1001-1100 MST							
4.3	6.3	1.32	264	16.7	21.6	0.41	0.21
19.5	7.2	1.60	263	14.9	--	--	0.22
31.7	7.7	1.55	266	15.0	20.6	0.27	0.20
62.0	7.5	1.46	266	13.1	20.0	0.23	0.20
1101-1200 MST							
4.3	4.7	1.52	268	19.8	22.5	0.38	0.32
19.5	5.3	1.64	265	17.8	--	--	0.31
31.7	5.8	1.64	268	15.1	21.4	0.35	0.28
62.0	5.7	1.60	267	15.3	20.9	0.33	0.28
1201-1300 MST							
4.3	4.8	1.79	281	27.3	22.9	0.40	0.37
19.5	5.5	1.95	278	21.1	--	--	0.35
31.7	5.9	1.99	280	17.5	21.8	0.27	0.34
62.0	5.9	1.82	279	16.6	21.4	0.26	0.31

TABLE IV (Continued)

WIND AND TEMPERATURE DATA FOR 1001-1600 MST BY THE HOUR, 15 MARCH 1961

1301-1400

z Height (meters)	$\bar{u}$ Wind Speed (m sec^{-1})	$\sigma_{\bar{u}}$ Standard Deviation (m sec^{-1})	$\bar{A}$ Wind Direction (degrees)	$\sigma_{\bar{A}}$ Standard Deviation (degrees)	$\bar{T}$ Temperature (degrees C)	$\sigma_{\bar{T}}$ Standard Deviation (degrees C)	I Gustiness Ratio
4.3	5.5	1.61	276	19.2	23.3	0.34	0.29
19.5	6.4	1.94	273	15.1	--	--	0.30
31.7	6.9	1.90	276	15.0	22.0	0.32	0.27
62.0	7.0	1.74	276	15.0	21.7	0.27	0.25

1401-1500

4.3	4.9	1.45	283	18.7	24.1	0.35	0.30
19.5	5.6	1.61	281	15.8	23.2	0.43	0.29
31.7	6.1	1.68	284	14.9	24.6	0.47	0.28
62.0	6.0	1.67	284	14.2	22.7	0.45	0.28

1501-1600

4.3	4.5	1.44	256	23.9	24.5	0.30	0.32
19.5	5.1	1.60	255	21.8	23.7	0.28	0.31
31.7	5.5	1.69	257	21.2	23.5	0.29	0.31
62.0	5.6	1.69	260	22.2	23.2	0.22	0.30

TABLE V

WIND AND TEMPERATURE DATA FOR 1801-2400 MST BY THE HOUR, 16 MARCH 1961

z Height (meters)	$\bar{u}$ Wind Speed (m sec^{-1})	$\sigma_{\bar{u}}$ Standard Deviation (m sec^{-1})	$\bar{A}$ Wind Direction (degrees)	$\sigma_{\bar{A}}$ Standard Deviation (degrees)	$\bar{T}$ Temperature (degrees C)	$\sigma_{\bar{T}}$ Standard Deviation (degrees C)	I Gustiness Ratio
1801-1900 MST							
4.3	4.5	1.52	323	18.1	7.8	0.26	0.34
19.5	6.2	2.10	316	17.0	7.6	0.32	0.34
31.7	6.4	2.15	318	15.9	7.4	0.26	0.33
62.0	7.3	2.41	321	14.2	7.3	0.22	0.33
1901-2000 MST							
4.3	3.5	1.39	304	17.4	6.7	0.32	0.40
19.5	5.1	1.61	297	13.9	6.7	0.26	0.32
31.7	5.4	1.61	298	12.5	6.5	0.23	0.30
62.0	6.7	1.65	298	9.3	6.4	0.19	0.25
2001-2100 MST							
4.3	4.7	0.94	293	11.8	7.3	0.30	0.21
19.5	7.0	1.16	289	8.2	7.4	0.34	0.17
31.7	8.0	1.12	291	8.2	7.4	0.35	0.14
62.0	9.5	1.03	296	3.5	7.6	0.34	0.11

TABLE V (Continued)

WIND AND TEMPERATURE DATA FOR 1801-2400 MST BY THE HOUR, 16 MARCH 1961

z Height (meters)	$\bar{u}$ Wind Speed (m sec^{-1})	$\sigma_{\bar{u}}$ Standard Deviation (m sec^{-1})	$\bar{A}$ Wind Direction (degrees)	$\sigma_{\bar{A}}$ Standard Deviation (degrees)	$\bar{T}$ Temperature (degrees C)	$\sigma_{\bar{T}}$ Standard Deviation (degrees C)	I Gustiness Ratio
			2101-2200 MST				
4.3	4.1	1.12	302	21.9	7.2	0.40	0.27
19.5	6.5	1.61	295	12.9	7.5	0.35	0.25
31.7	7.3	1.74	298	10.0	7.5	0.35	0.24
62.0	8.4	1.79	297	6.0	7.6	0.31	0.21
			2201-2300 MST				
4.3	3.5	1.61	319	23.0	7.2	0.39	0.46
19.5	5.3	2.28	306	18.1	7.4	0.30	0.43
31.7	5.9	2.68	304	14.7	7.4	0.30	0.46
62.0	7.7	3.08	299	11.5	7.5	0.29	0.40
			2301-2400 MST				
4.3	6.0	1.03	295	6.3	7.7	0.13	0.17
19.5	9.1	1.16	288	4.1	7.8	0.11	0.13
31.7	10.2	1.07	291	3.4	7.8	0.12	0.10
62.0	12.2	0.80	293	2.5	7.9	0.09	0.07

TABLE VI

WIND AND TEMPERATURE DATA PER 10 MINUTE INTERVAL
12 FEBRUARY 1958
1001-1100 MST

TIME-MST	1001-1010			1011-1020			1021-1030			1031-1040			1041-1050			1051-1100		
z Height (meters)	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$
4.6	3.4	176	3.6	3.5	173	3.8	3.7	184	4.0	3.8	179	4.3	3.8	171	4.6	3.4	187	5.0
11.9	4.3	179	3.0	4.4	172	3.2	4.6	179	3.4	4.7	177	3.8	4.7	170	3.9	4.4	184	4.7
19.3	4.5	176	2.9	4.7	169	3.1	4.7	180	3.2	4.8	174	3.6	4.7	166	3.9	4.4	177	4.3
26.6	4.8	176	2.6	4.9	170	2.8	4.9	181	3.0	5.1	178	3.3	4.9	171	3.6	4.8	184	3.9
33.9	4.9	176	2.6	5.0	172	2.8	5.1	183	3.0	5.2	178	3.2	5.0	172	3.6	4.8	185	3.9
41.2	4.9	177	2.6	5.1	172	2.8	5.2	184	2.9	5.3	180	3.3	5.1	173	3.6	4.9	186	3.9
48.5	4.8	175	2.4	5.1	175	2.4	5.2	183	2.6	5.2	180	2.9	5.1	173	3.4	4.9	185	3.6
55.8	4.8	176	2.2	5.1	174	2.6	5.2	182	2.8	5.2	178	3.0	5.1	174	3.2	4.8	185	3.7
62.0	5.0	174	2.1	5.4	173	2.4	5.3	179	2.6	-	-	2.9	5.3	176	3.2	4.9	173	3.6

Remarks: Wind speeds in m sec^{-1}; Temperatures in degrees C.

TABLE VII

WIND AND TEMPERATURE DATA PER 10 MINUTE INTERVAL
13 February 1958
1202-1301 MST

TIME-MST	1202-1211			1212-1221			1222-1231			1232-1241			1242-1251			1252-1301		
z Height (meters)	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$
4.6	2.6	216	12.1	5.2	251	12.0	5.2	244	12.4	5.4	254	13.2	7.6	259	13.6	5.9	253	13.8
11.9	3.2	214	11.6	6.8	246	11.6	7.0	239	11.8	6.9	251	12.4	9.4	255	12.6	7.0	249	12.8
19.3	3.4	211	11.8	7.5	245	11.9	7.7	239	12.1	7.5	249	12.8	10.4	255	13.0	7.4	298	13.2
26.6	3.4	211	11.3	7.9	247	11.3	8.0	241	11.6	7.9	249	12.7	10.8	255	12.2	8.0	248	12.5
33.9	3.6	215	11.5	8.3	251	11.5	8.3	245	11.8	8.2	252	12.3	11.2	258	12.1	8.1	250	12.6
41.2	3.8	213	11.5	8.8	253	11.5	8.5	246	11.8	8.6	253	12.2	11.6	259	12.2	8.2	252	12.4
48.5	3.9	222	11.4	9.0	252	11.4	8.6	247	11.6	8.6	253	12.1	11.8	259	12.2	8.4	251	12.4
55.8	4.0	221	11.3	9.2	251	11.3	8.6	246	11.6	8.8	252	11.9	12.0	258	11.7	8.4	251	12.1
62.0	4.2	227	11.3	9.6	253	11.3	9.0	250	11.5	9.0	254	12.4	12.4	259	11.7	8.8	251	11.9

Remarks: Wind speeds in m sec^{-1}; Temperatures in degrees C.

TABLE VIII

WIND AND TEMPERATURE DATA PER 10 MINUTE INTERVAL
7 March 1958
1334-1433 MST

TIME-MST	1334-1343			1344-1353			1354-1403			1404-1413			1414-1423			1424-1433		
z Height (meters)	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$
4.6	9.6	283	5.6	9.6	282	5.0	8.9	286	4.7	8.4	284	4.3	7.8	277	4.6	7.6	285	4.4
11.9	12.2	284	5.4	12.2	280	5.2	11.8	284	4.9	10.1	284	4.4	9.6	275	4.2	9.7	283	4.5
19.3	14.0	282	5.3	13.8	278	4.8	13.3	282	4.5	11.5	281	4.1	10.8	274	4.5	11.9	281	4.3
26.6	15.1	281	5.3	14.7	278	4.8	13.8	282	4.3	12.4	282	3.7	12.1	275	4.3	12.2	281	4.2
33.9	16.0	283	5.2	15.5	280	4.6	14.6	283	4.2	12.9	284	3.8	12.3	276	4.2	12.7	284	4.0
41.2	16.7	287	5.2	16.0	287	4.6	15.0	284	4.2	13.2	284	3.9	13.0	277	4.2	13.0	283	4.0
48.5	17.4	282	5.1	16.5	280	4.7	15.6	283	4.2	13.8	283	3.8	13.6	275	4.2	13.6	282	3.9
55.8	17.7	282	5.0	16.9	280	4.6	15.8	282	4.1	14.0	283	3.8	14.0	276	4.1	14.0	282	3.9
62.0	18.2	284	4.9	17.4	282	4.6	16.4	285	4.1	14.5	286	3.7	14.4	277	4.1	14.2	284	3.9

Remarks: Wind speed in m sec^{-1}; Temperature in degrees C.

TABLE IX

WIND AND TEMPERATURE DATA PER 10 MINUTE INTERVAL, 15 MARCH 1961

Height, meters	4.3			19.5			31.7			62.0		
Time, MST	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$
1001-1010	6.6	271	21.1	7.8	271	-	8.2	274	20.4	7.8	273	19.9
1011-1020	6.4	268	21.4	7.4	268	-	7.8	271	20.6	7.6	272	20.0
1021-1030	6.4	270	21.6	7.5	270	-	8.0	273	20.4	7.9	273	19.9
1031-1040	5.8	258	21.6	6.2	261	-	6.1	264	20.5	6.8	261	19.8
1041-1050	5.7	263	22.0	6.4	262	-	6.9	265	20.8	6.6	261	20.3
1051-1100	7.0	250	21.8	7.9	248	-	8.4	252	20.6	8.2	253	20.2
1101-1110	4.9	262	22.1	5.4	261	-	5.9	265	20.9	6.0	266	20.4
1111-1120	5.4	265	22.4	5.7	264	-	6.1	266	21.4	6.0	263	20.9
1121-1130	4.8	271	22.4	5.5	266	-	6.0	268	21.4	6.0	265	20.8
1131-1140	4.1	254	22.7	4.4	253	-	4.8	253	21.5	4.6	259	21.0
1141-1150	4.3	268	22.6	4.7	263	-	5.2	271	21.6	5.2	271	21.1
1151-1200	5.0	286	22.8	6.1	281	-	6.6	283	21.7	6.7	281	21.3
1201-1210	5.4	279	22.9	6.3	273	-	6.9	280	21.8	6.6	277	21.3
1211-1220	5.4	278	22.4	6.2	273	-	6.5	274	21.6	6.2	276	21.2
1221-1230	4.7	290	22.9	5.4	284	-	5.8	286	21.7	5.6	283	21.3
1231-1240	4.0	263	23.1	4.4	268	-	4.7	272	22.0	4.2	284	21.7
1241-1250	4.9	284	23.1	5.7	282	-	6.2	284	21.7	6.2	286	21.3
1251-1300	4.5	289	23.1	5.0	286	-	5.4	283	21.9	5.6	281	21.6
1301-1310	6.0	280	23.2	7.4	276	-	7.9	279	21.8	7.8	279	21.6
1311-1320	5.1	282	22.9	6.1	279	-	6.7	280	21.7	6.7	278	21.3
1321-1330	6.0	285	23.5	7.0	283	-	7.6	286	22.2	7.8	287	21.7
1331-1340	6.1	265	23.6	7.0	266	-	7.3	268	22.3	7.3	270	21.9
1341-1350	5.3	258	23.2	5.9	258	22.5	6.4	262	22.2	6.3	262	21.9
1351-1400	4.6	283	23.2	5.3	277	22.4	5.7	279	22.0	6.0	281	21.7
1401-1410	5.0	287	23.6	6.0	284	22.5	6.4	288	22.2	6.4	289	21.9
1411-1420	3.8	286	24.0	4.3	289	23.1	4.9	291	22.8	4.5	288	22.6
1421-1430	4.7	282	24.1	5.7	280	23.2	6.2	284	22.9	6.1	283	22.6
1431-1440	5.5	283	24.2	6.5	280	23.3	7.0	283	23.1	6.8	283	22.8
1441-1450	5.1	287	24.2	5.8	285	23.4	6.4	288	23.2	6.5	289	22.9
1451-1500	4.9	269	24.4	5.3	269	23.8	5.6	271	23.6	5.4	271	23.2
1501-1510	4.0	238	24.6	4.4	238	23.7	4.6	238	23.3	5.0	241	23.1
1511-1520	4.5	266	24.3	5.3	263	23.4	5.9	266	23.2	6.0	266	22.9
1521-1530	4.8	266	24.3	5.4	265	23.6	5.5	257	23.2	5.7	265	23.0
1531-1540	4.4	256	24.7	5.1	255	23.9	5.7	267	23.7	5.5	264	23.2
1541-1550	4.1	244	24.7	4.9	244	24.0	5.4	248	23.8	5.5	250	23.3
1551-1600	4.9	267	24.5	5.5	264	23.8	6.0	267	23.7	5.8	269	23.3

Remarks: Wind speeds in m sec^{-1}. Temperatures in degrees C.

TABLE X

WIND AND TEMPERATURE DATA PER 10 MINUTE INTERVAL, 16 MARCH 1961

Height, meters	4.3			19.5			31.7			62.0		
Time, MST	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$	$\bar{u}$	$\bar{A}$	$\bar{T}$
1801-1810	4.7	338	7.9	6.6	330	7.7	7.0	332	7.5	7.7	336	7.3
1811-1820	3.1	331	7.7	4.2	325	7.2	4.3	327	7.2	5.0	328	7.1
1821-1830	2.9	340	7.5	4.0	333	7.2	4.0	333	7.1	4.6	332	7.1
1831-1840	5.2	317	8.1	7.2	309	7.8	7.4	311	7.6	8.4	315	7.4
1841-1850	5.8	305	8.1	8.1	300	7.9	8.6	303	7.7	9.6	303	7.4
1851-1900	5.2	305	7.8	7.1	300	7.6	7.4	303	7.4	8.4	307	7.2
1901-1910	5.2	304	7.2	7.5	298	7.1	7.8	302	6.8	8.7	308	6.7
1911-1920	3.2	296	6.9	4.8	290	6.9	5.1	292	6.7	6.2	296	6.6
1921-1930	2.0	286	6.7	3.3	281	6.7	3.6	284	6.5	4.8	290	6.4
1931-1940	3.5	307	6.6	5.1	293	6.6	5.4	299	6.4	6.8	299	6.3
1941-1950	3.3	325	6.4	4.5	309	6.4	4.5	306	6.2	5.5	299	6.2
1951-2000	3.6	313	6.3	5.1	305	6.3	5.7	303	6.2	7.8	299	6.2
2001-2010	3.5	305	6.8	5.5	296	6.8	6.5	295	6.1	9.5	297	6.9
2011-2020	4.7	296	7.3	7.5	290	7.4	8.7	294	7.3	10.6	298	7.7
2021-2030	4.7	294	7.6	7.1	291	7.6	8.0	293	7.6	9.4	298	7.7
2031-2040	4.7	292	7.6	7.2	288	7.7	7.9	292	7.6	9.2	295	7.7
2041-2050	4.3	289	7.4	7.0	285	7.7	8.0	290	7.6	9.2	294	7.7
2051-2100	4.8	283	7.2	7.4	281	7.4	8.6	285	7.4	10.4	290	7.7
2101-2110	5.5	287	7.7	8.7	283	7.8	9.8	287	7.8	11.2	291	7.9
2111-2120	4.7	290	7.6	7.3	287	7.7	8.3	290	7.7	9.1	293	7.8
2121-2130	4.4	292	7.3	7.0	288	7.6	7.8	291	7.7	9.0	293	7.7
2131-2140	3.7	298	7.1	6.3	293	7.7	7.1	294	7.7	7.7	297	7.7
2141-2150	3.3	319	6.9	5.5	307	7.3	6.2	307	7.3	7.5	306	7.4
2151-2200	2.8	328	6.7	4.4	315	6.9	4.6	313	6.9	6.0	304	7.1
2201-2210	2.5	335	6.6	4.0	319	7.0	4.1	316	6.9	5.6	304	7.2
2211-2220	2.4	341	6.9	3.6	322	7.3	3.7	317	7.3	4.9	307	7.4
2221-2230	2.8	338	7.1	3.8	321	7.3	3.8	317	7.3	5.3	307	7.2
2231-2240	2.9	313	7.2	4.5	300	7.4	5.0	299	7.3	7.2	297	7.4
2241-2250	4.6	300	7.6	7.0	291	7.8	8.0	291	7.7	10.7	293	7.7
2251-2300	6.0	291	7.7	9.0	284	7.8	10.2	287	7.8	12.6	290	7.9
2301-2310	5.7	294	7.7	9.1	287	7.8	10.3	290	7.8	12.4	293	7.9
2311-2320	6.5	297	7.6	9.4	289	7.7	10.3	296	7.7	12.7	294	7.9
2321-2330	5.4	296	7.7	8.3	290	7.8	9.4	291	7.7	11.4	294	7.8
2331-2340	5.7	294	7.7	8.7	286	7.8	9.7	289	7.7	11.9	293	7.8
2341-2350	6.3	295	7.9	9.6	288	8.0	10.7	290	7.9	12.4	292	8.0
2351-2400	6.1	295	7.9	9.5	288	7.9	10.7	290	7.9	12.2	293	8.0

Remarks: Wind speeds in m sec^{-1}. Temperatures in degrees C.

TABLE XI

BOUNDARY PARAMETERS BY 10 MINUTE INTERVALS, 12 FEBRUARY 1958

t Time Interval MST	P Pressure mb	ρ Density gm cm^{-3}	z_o Roughness Length cm	u_* Friction Velocity cm sec^{-1}	C_D Coefficient of Drag	τ_o Surface Stress dynes cm^{-2}	K_M Eddy Viscosity cm^2 sec^{-1} x 10^4	N Macro-Viscosity cm^2 sec^{-1}
1001-1010	883.9	1113.4	4.5	29	0.015	0.970	0.534	150.5
1011-1020	883.9	1112.6	4.6	30	0.015	1.02	0.552	158.0
1021-1030	883.9	1111.8	4.8	32	0.015	1.14	0.589	153.6
1031-1040	883.9	1110.6	4.9	33	0.015	1.20	0.607	161.7
1041-1050	883.9	1109.5	4.9	33	0.015	1.20	0.607	161.7
1051-1100	883.9	1107.8	4.5	29	0.015	0.96	0.534	150.5

TABLE XII

BOUNDARY PARAMETERS BY 10 MINUTE INTERVALS, 13 FEBRUARY 1958

t Time Interval MST	P Pressure mb	ρ Density gm cm^{-3}	z_o Roughness Length cm	u_* Friction Velocity cm sec^{-1}	C_D Coefficient of Drag	τ_o Surface Stress dynes cm^{-2}	K_M Eddy Viscosity cm^2 sec^{-1} x 10^4	N Macro-Viscosity cm^2 sec^{-1}
1202-1211	869.3	1062.4	3.7	22	0.014	0.50	0.405	81.4
1212-1221	869.3	1062.8	7.2	50	0.018	2.59	0.920	360.0
1222-1231	869.3	1061.3	7.2	50	0.018	2.58	0.920	360.0
1232-1241	869.3	1058.3	7.5	52	0.019	2.93	0.957	390.0
1242-1251	869.3	1056.9	13.0	85	0.024	7.33	1.564	1105.0
1252-1301	869.3	1056.1	8.2	56	0.019	3.26	1.030	459.2

TABLE XIII

BOUNDARY PARAMETERS BY 10 MINUTE INTERVALS, 7 MARCH 1958

t Time Interval MST	P Pressure mb	ρ Density gm cm^{-3}	z_o Roughness Length cm	$\bar{u}_*$ Friction Velocity cm sec^{-1}	C_D Coefficient of Drag	τ_o Surface Stress dynes cm^{-2}	K_M Eddy Viscosity cm^2 sec^{-1} x 10^4	N Macro-Viscosity cm^2 sec^{-1}
1334-1343	870.1	1088.2	21.4	123	0.032	16.04	2.263	2632.2
1344-1353	870.1	1090.5	21.4	123	0.032	16.08	2.263	2632.2
1354-1403	870.1	1091.7	17.8	108	0.029	12.54	1.987	1922.4
1404-1413	870.1	1093.2	15.8	99	0.028	10.80	1.822	1564.2
1414-1423	870.1	1092.1	13.7	88	0.025	8.31	1.619	1205.6
1424-1433	870.1	1092.9	13.0	85	0.025	7.89	1.564	1105.0

TABLE XIV

BOUNDARY PARAMETERS BY 10-MINUTE INTERVALS, 15 MARCH 1961

t Time Interval MST	P Pressure mb	ρ Density gm cm^{-3}	z_o Roughness Length cm	u_* Friction Velocity cm sec^{-1}	C_D Coefficient of Drag	τ_o Surface Stress dynes cm^{-2}	K_M Eddy Viscosity cm^2 sec^{-1} x 10^4	N Macro-Viscosity cm^2 sec^{-1}
1001-1010	877.3	1039.4	10.0	70	0.022	4.98	1.288	700.0
1011-1020	877.3	1038.3	9.5	68	0.022	4.68	1.251	646.0
1021-1030	877.3	1037.6	9.5	68	0.022	4.68	1.251	646.0
1031-1040	877.3	1037.6	8.4	60	0.021	3.67	1.104	504.0
1041-1050	877.3	1035.5	8.2	58	0.021	3.53	1.067	475.6
1051-1100	877.3	1036.1	11.2	78	0.025	6.35	1.435	873.6
1101-1110	877.1	1034.9	6.6	48	0.019	2.36	0.883	316.8
1111-1120	876.8	1033.8	7.5	54	0.020	3.01	0.994	405.0
1121-1130	876.4	1033.4	6.5	46	0.018	2.14	0.846	299.0
1131-1140	876.0	1031.6	5.4	38	0.017	1.47	0.699	205.2
1141-1150	875.7	1031.6	5.6	40	0.017	1.62	0.736	224.0
1151-1200	875.4	1030.5	6.8	49	0.019	2.45	0.902	333.2
1201-1210	875.1	1029.8	7.5	54	0.020	3.00	0.994	405.0
1211-1220	874.8	1031.1	7.5	54	0.020	3.01	0.994	405.0
1221-1230	874.5	1029.1	6.3	45	0.018	2.05	0.828	283.5
1231-1240	874.2	1028.0	5.3	37	0.017	1.40	0.681	196.1
1241-1250	873.9	1027.6	6.6	48	0.019	2.34	0.883	316.8
1251-1300	873.6	1027.3	6.0	43	0.018	1.87	0.791	258.0

TABLE XIV (Continued)

BOUNDARY PARAMETERS BY 10-MINUTE INTERVALS, 15 MARCH 1961

t Time Interval MST	P Pressure mb	ρ Density gm cm^{-3}	z_o Roughness Length cm	u_* Friction Velocity cm sec^{-1}	C_D Coefficient of Drag	τ_o Surface Stress dynes cm^{-2}	K_M Eddy Viscosity cm^2 sec^{-1} x 10^4	N Macro-Viscosity cm^2 sec^{-1}
1301-1310	873.4	1026.3	8.8	63	0.022	4.06	1.159	554.4
1311-1320	873.3	1027.7	7.0	50	0.019	2.54	0.920	350.0
1321-1330	873.2	1025.5	8.8	63	0.022	4.06	1.159	554.4
1331-1340	873.1	1025.0	9.0	64	0.022	4.20	1.178	576.0
1341-1350	873.0	1026.2	7.4	53	0.020	2.88	0.975	392.2
1351-1400	872.9	1026.1	6.1	44	0.018	1.95	0.810	268.4
1401-1410	872.8	1024.7	6.8	49	0.019	2.43	0.902	333.2
1411-1420	872.7	1023.1	5.0	34	0.016	1.18	0.585	170.0
1421-1430	872.6	1022.6	6.3	45	0.018	2.03	0.774	283.5
1431-1440	872.5	1022.3	7.8	55	0.020	3.09	0.946	429.0
1441-1450	872.4	1022.1	7.0	50	0.019	2.53	0.860	350.0
1451-1500	872.3	1021.3	6.6	48	0.019	2.33	0.826	316.8
1501-1510	872.2	1020.5	5.3	37	0.017	1.39	0.636	196.1
1511-1520	872.1	1020.7	6.0	43	0.018	1.86	0.740	258.0
1521-1530	872.0	1021.3	6.5	46	0.018	2.12	0.791	299.0
1531-1540	871.9	1019.8	5.8	41	0.017	1.68	0.705	237.8
1541-1550	871.8	1019.6	5.4	38	0.017	1.46	0.654	205.2
1551-1600	871.7	1020.2	6.6	48	0.019	2.33	0.826	316.8

TABLE XV

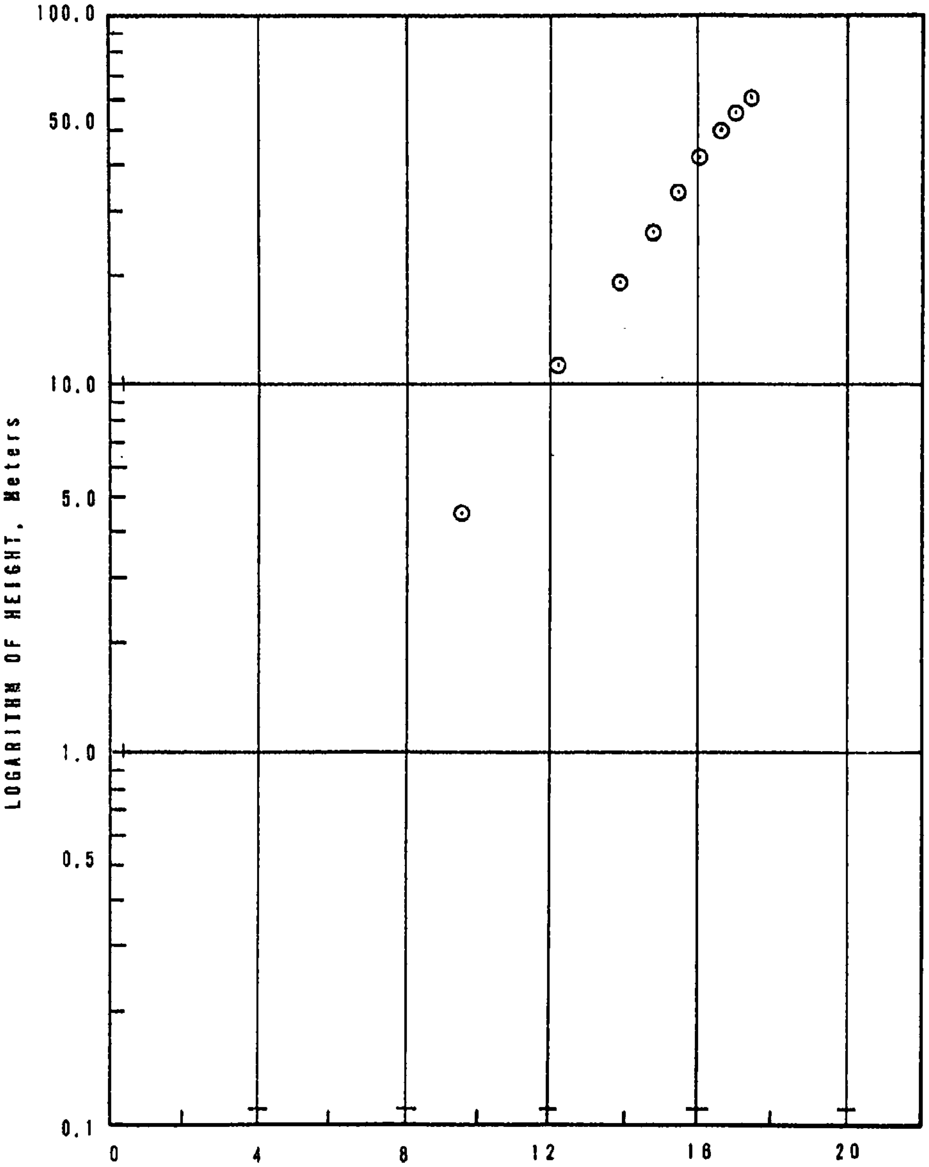
BOUNDARY PARAMETERS BY 10-MINUTE INTERVALS, 16 MARCH 1961

t Time Interval MST	P Pressure mb	ρ Density gm cm^{-3}	z_o Roughness Length cm	u_* Friction Velocity cm sec^{-1}	C_D Coefficient of Drag	τ_o Surface Stress dynes cm^{-2}	K_M Eddy Viscosity cm^2 sec^{-1} x 10^4	N Macro-Viscosity cm^2 sec^{-1}
1801-1810	871.8	1080.6	6.3	45	0.018	2.14	0.774	283.5
1811-1820	871.8	1081.4	4.2	27	0.015	0.78	0.464	113.4
1821-1830	871.8	1082.2	4.0	25	0.015	0.68	0.430	100.0
1831-1840	871.8	1079.9	7.1	50	0.019	2.76	0.860	355.0
1841-1850	871.8	1079.9	8.4	60	0.021	3.81	1.032	504.0
1851-1900	871.8	1081.0	7.1	50	0.019	2.65	0.860	355.0
1901-1910	871.8	1083.4	7.1	50	0.019	2.65	0.860	355.0
1911-1920	871.8	1084.5	4.3	28	0.015	0.83	0.482	120.4
1921-1930	871.8	1085.3	3.2	16	0.013	0.28	0.275	51.2
1931-1940	871.8	1085.7	4.6	31	0.016	1.06	0.533	142.6
1941-1950	871.8	1086.4	4.4	29	0.015	0.89	0.499	127.6
1951-2000	871.8	1086.8	4.7	32	0.016	1.13	0.550	150.4
2001-2010	871.8	1084.9	4.6	31	0.016	1.06	0.533	142.6
2011-2020	871.8	1083.0	6.3	45	0.018	2.15	0.774	283.5
2021-2030	871.8	1081.8	6.3	45	0.018	2.15	0.774	283.5
2031-2040	871.8	1081.8	6.3	45	0.018	2.15	0.774	283.5
2041-2050	871.8	1082.6	5.6	40	0.017	1.70	0.688	224.0
2051-2100	871.8	1083.4	6.5	46	0.018	2.25	0.791	299.0

TABLE XV (Continued)

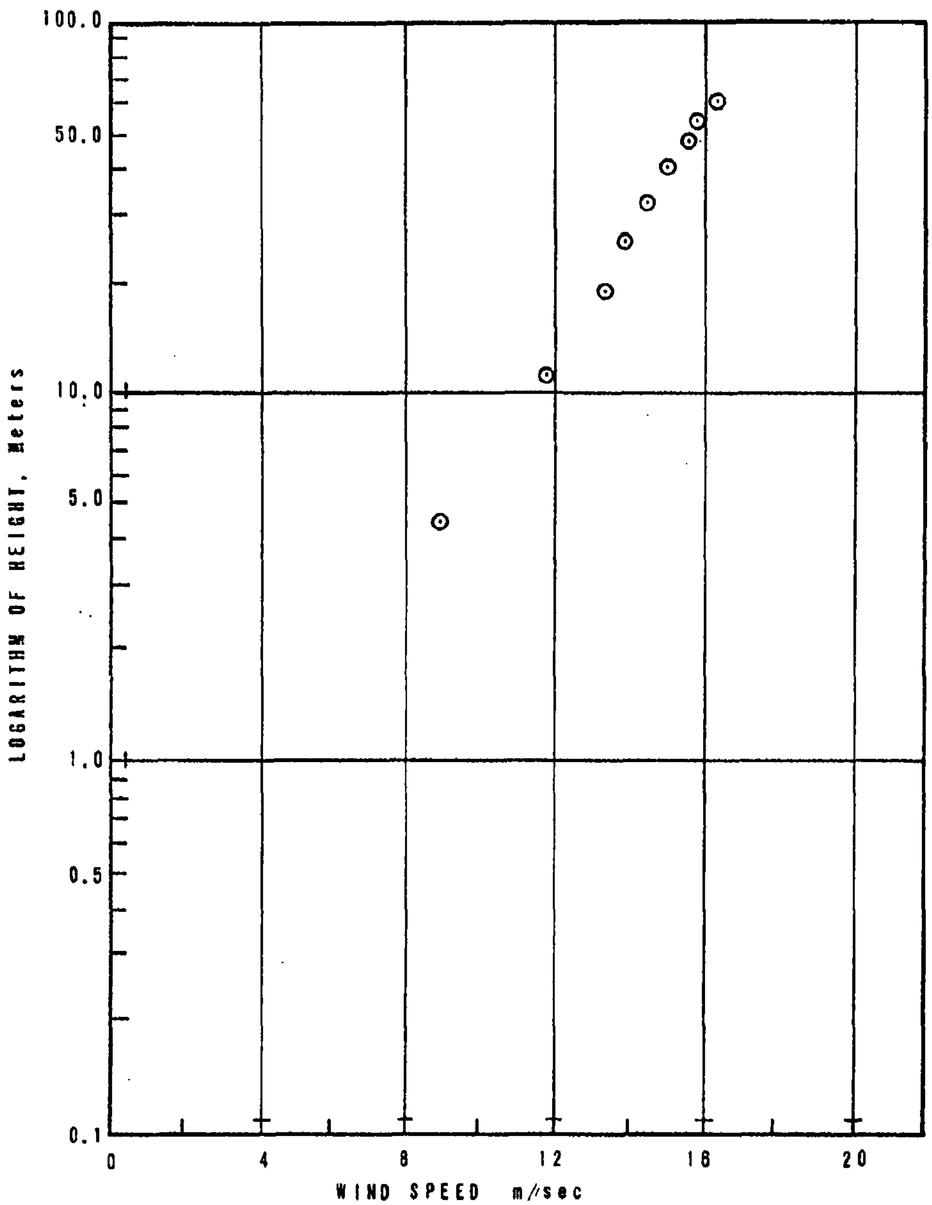
BOUNDARY PARAMETERS BY 10-MINUTE INTERVALS, 16 MARCH 1961

t Time Interval MST	P Pressure mb	ρ Density gm cm^{-3}	z_o Roughness Length cm	u_* Friction Velocity cm sec^{-1}	C_D Coefficient of Drag	τ_o Surface Stress dynes cm^{-2}	K_M Eddy Viscosity cm^2 sec^{-1} x 10^4	N Macro-Viscosity cm^2 sec^{-1}
2101-2110	871.8	1081.4	7.7	55	0.020	3.27	0.946	423.5
2111-2120	871.8	1081.8	6.3	45	0.018	2.15	0.774	283.5
2121-2130	871.8	1083.0	5.8	41	0.017	1.78	0.705	237.8
2131-2140	871.8	1083.8	4.8	32	0.015	1.11	0.550	153.6
2141-2150	871.8	1084.5	4.4	30	0.017	1.00	0.516	132.0
2151-2200	871.8	1085.3	3.9	24	0.015	0.64	0.413	93.6
2201-2210	871.8	1085.7	3.6	21	0.014	0.47	0.361	75.6
2211-2220	871.8	1084.5	3.5	20	0.014	0.44	0.344	70.0
2221-2230	871.8	1083.8	3.9	23	0.013	0.55	0.396	89.7
2231-2240	871.8	1083.4	4.0	25	0.015	0.68	0.430	100.0
2241-2250	871.8	1081.8	6.2	43	0.017	1.95	0.740	266.6
2251-2300	871.8	1081.4	8.8	63	0.022	4.28	1.084	554.4
2301-2310	871.8	1081.4	8.2	58	0.021	3.69	0.998	475.6
2311-2320	871.8	1081.8	10.0	68	0.022	5.03	1.170	680.0
2321-2330	871.8	1081.4	7.5	54	0.020	3.15	0.929	405.0
2331-2340	871.8	1081.4	8.2	58	0.021	3.69	0.998	475.6
2341-2350	871.8	1080.6	9.5	66	0.022	4.72	1.135	627.0
2351-2400	871.8	1080.6	9.0	64	0.022	4.42	1.101	576.0



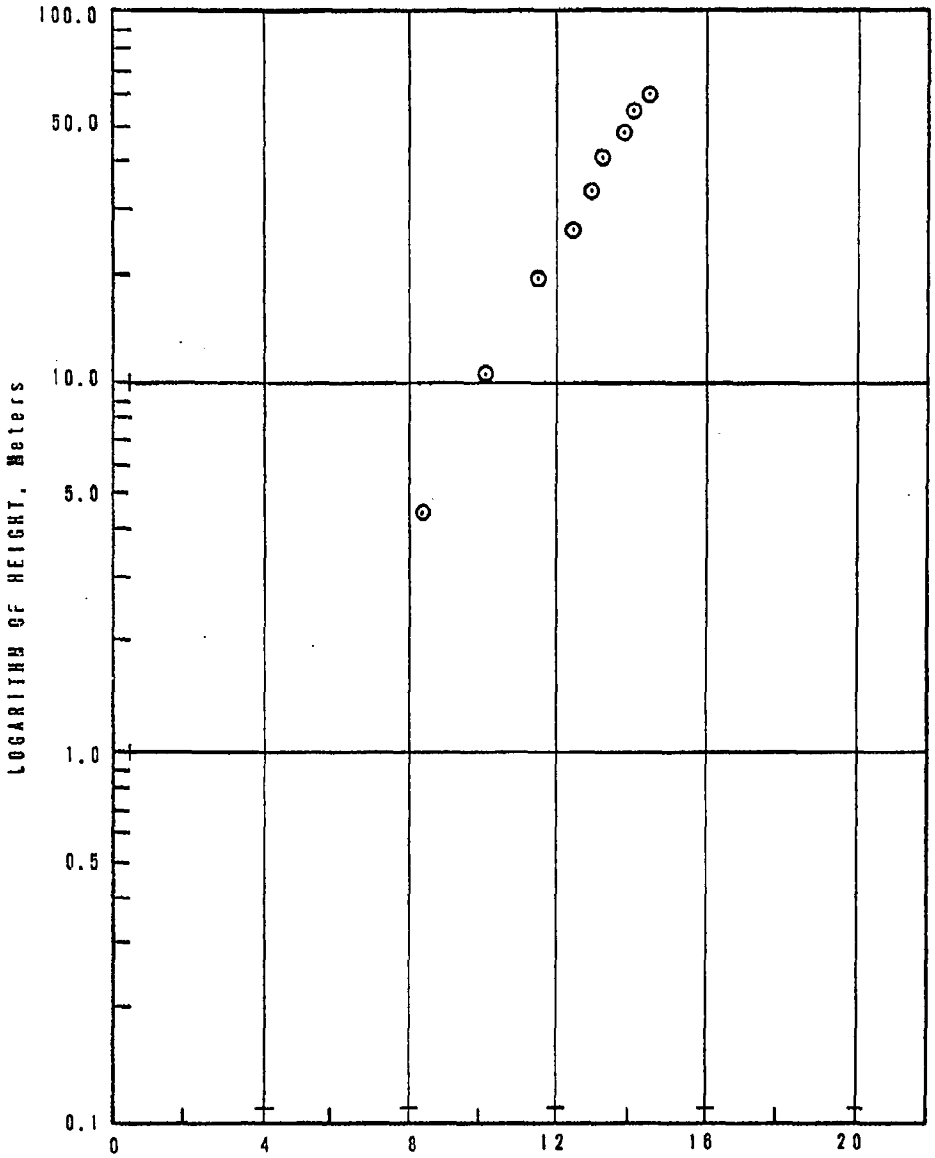
LOGARITHMIC WIND PROFILE, 1344 - 1353 MST
7 MARCH 1958, $y = 0.1933e^{0.3341x}$

Figure 1



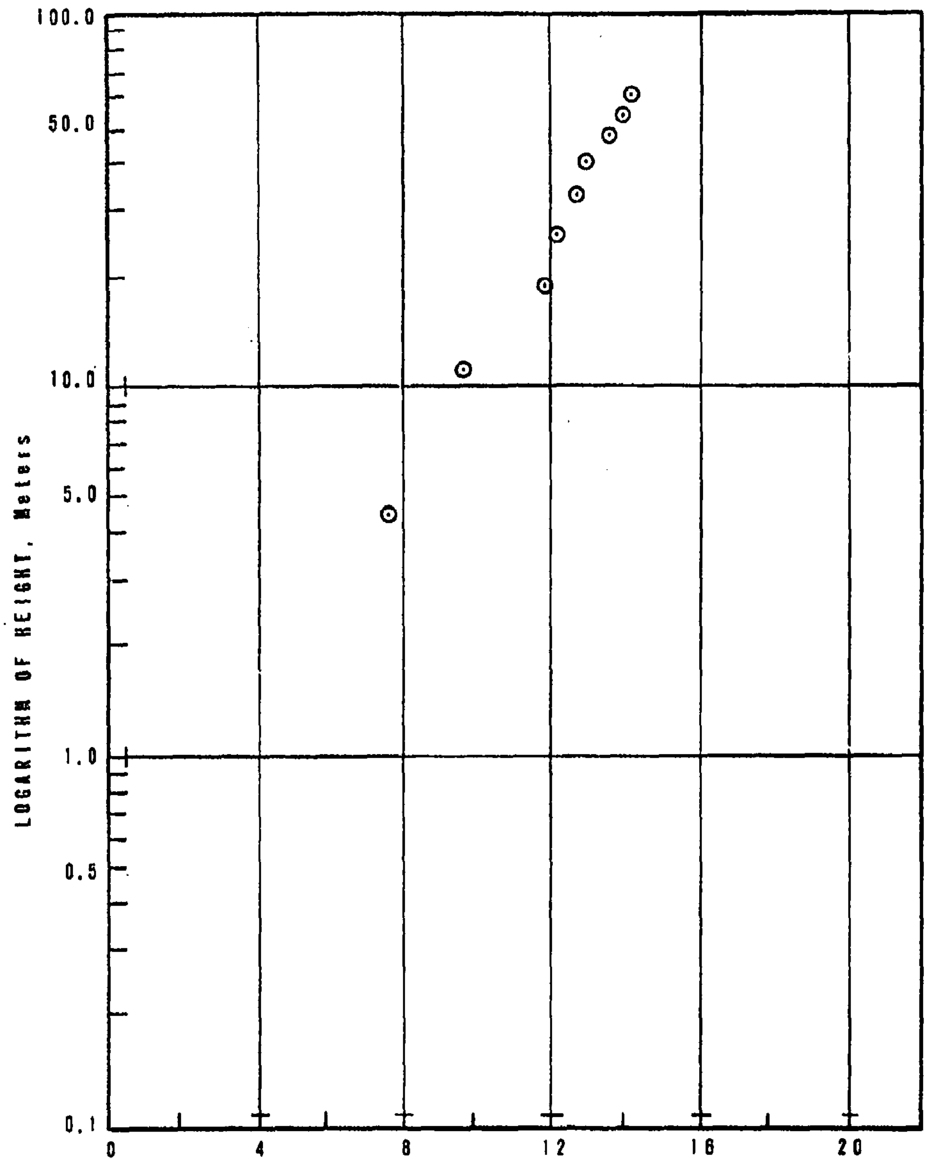
LOGARITHNIC WIND PROFILE, 1354 - 1403 MST
7 MARCH 1958, $y = 0.1841e^{0.3754x}$

Figure 2



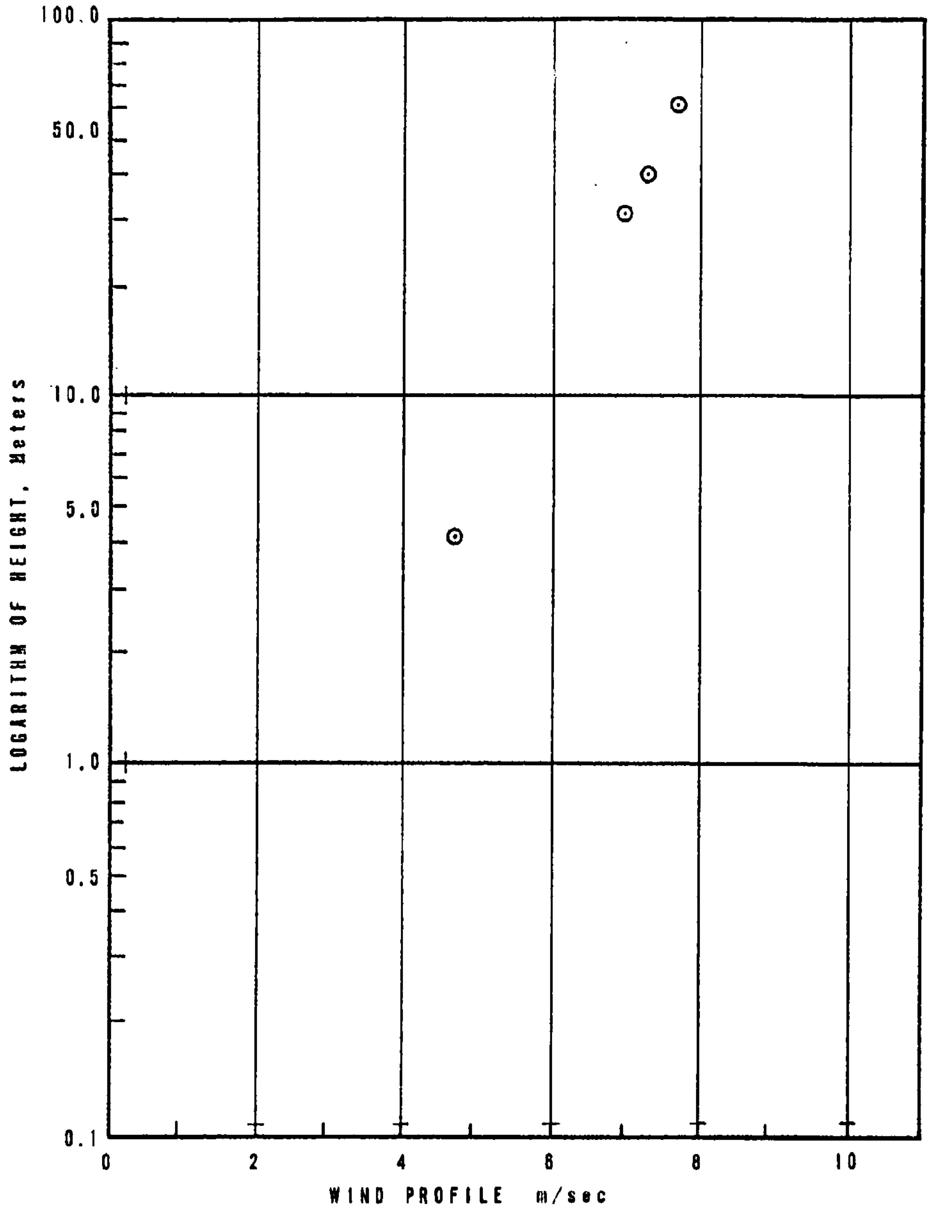
LOGARITHMIC WIND PROFILE FOR 1404 - 1413 MST
7 MARCH 1958, $y = 0.1498e^{0.4207x}$

Figure 3



LOGARITHMIC WIND PROFILE FOR 1424 - 1433 MST
7 MARCH 1958, $y = 0.2484e^{0.3861x}$

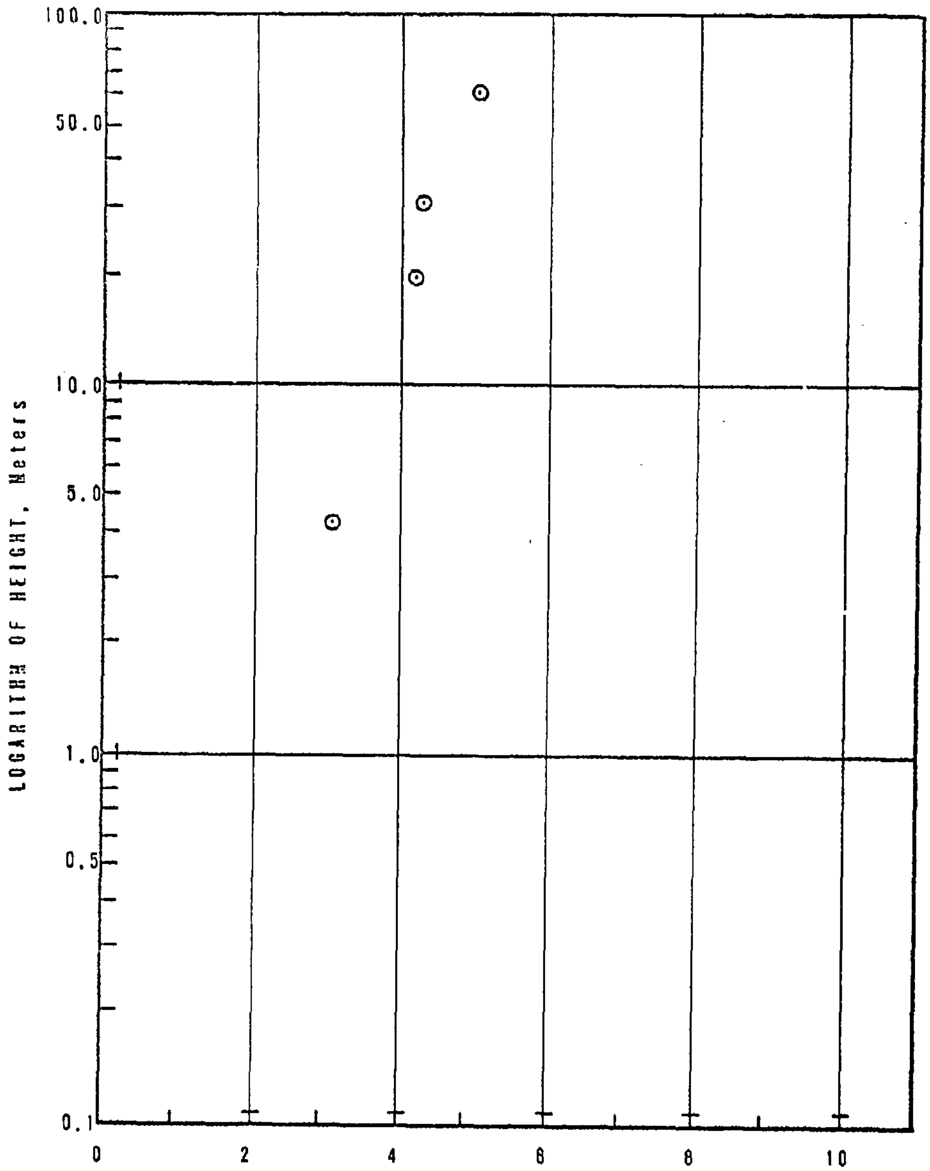
Figure 4



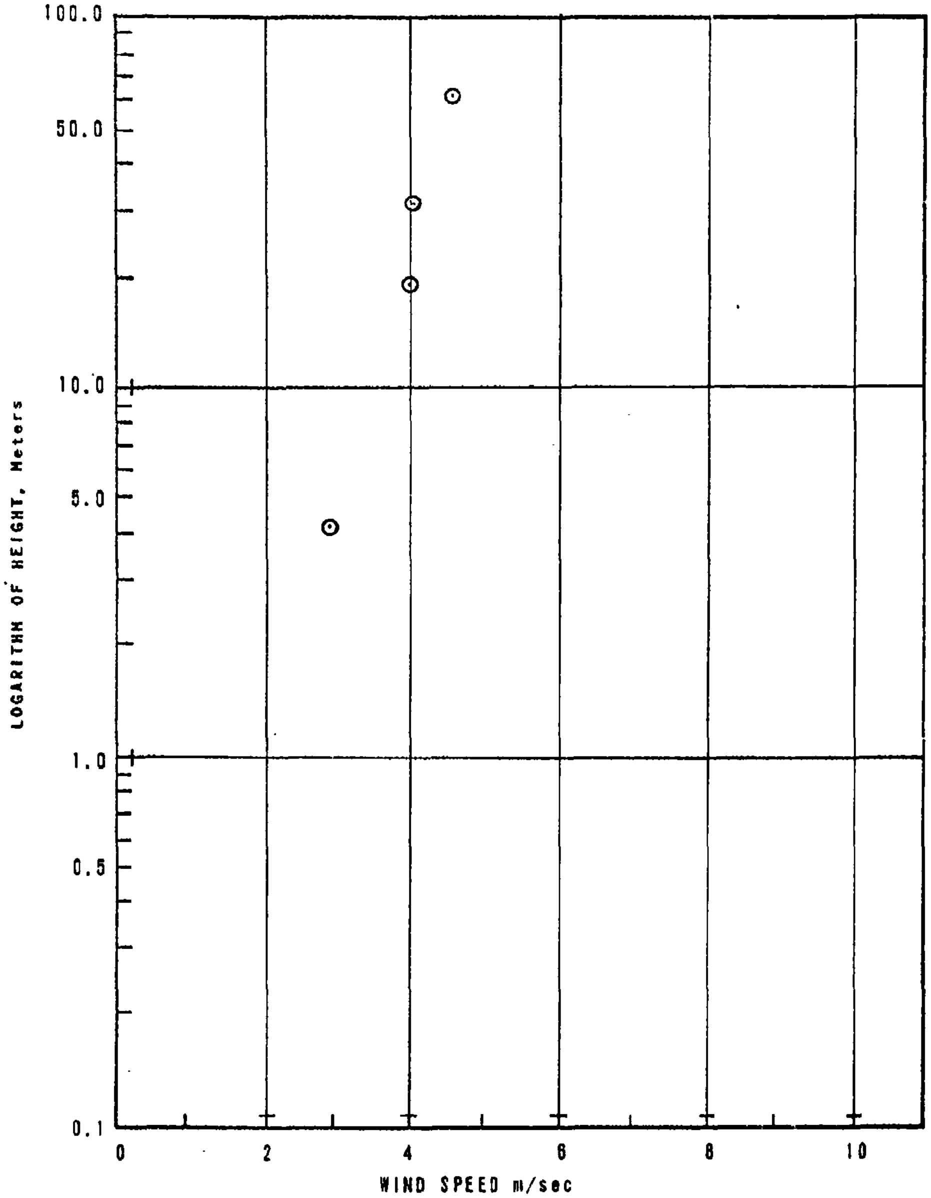
LOGARITHMIC WIND PROFILE FOR 1801 - 1810 MST

16 MARCH 1981, $y = 0.066e^{0.8851x}$

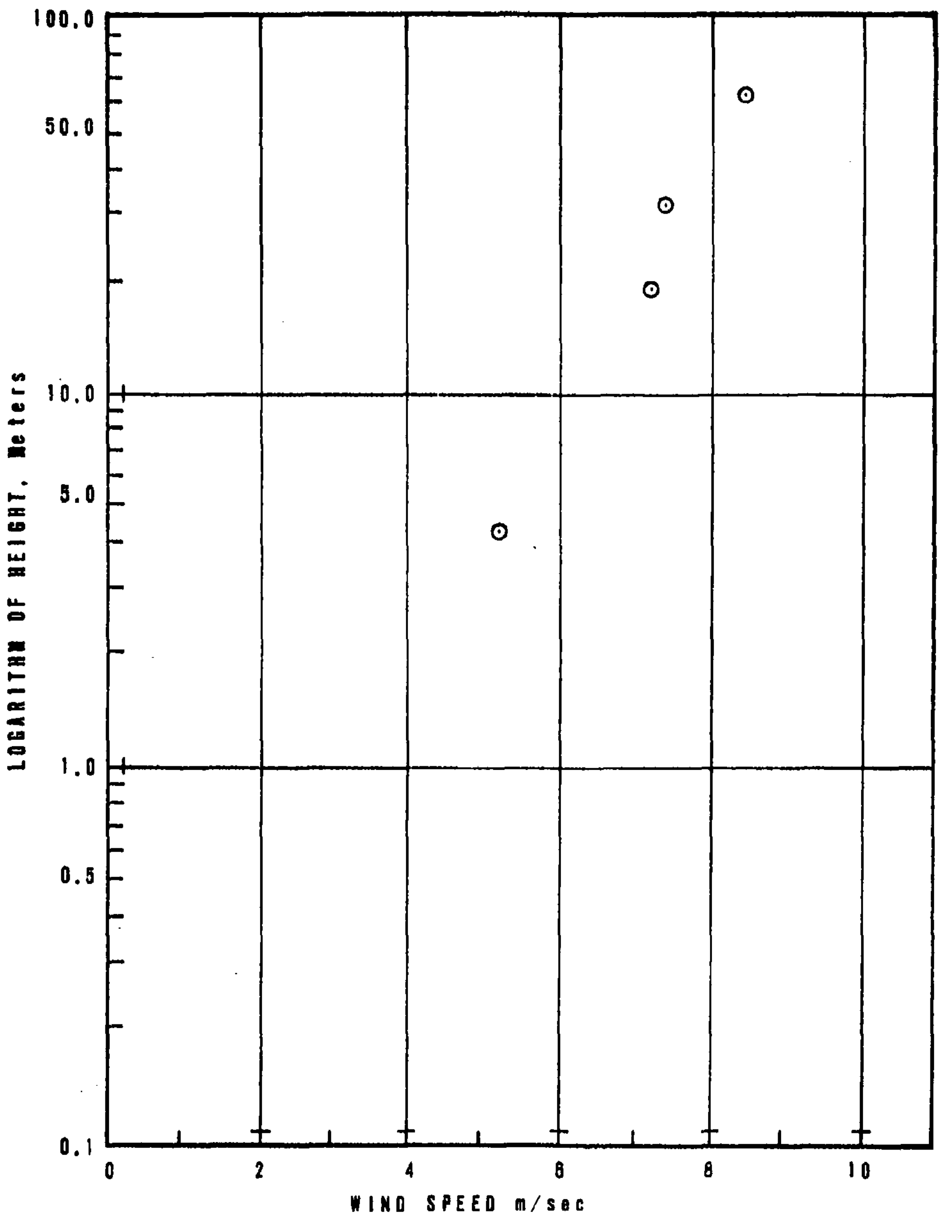
Figure 5



LOGARITHMIC WIND PROFILE FOR 1811 - 1820 MST
16 MARCH 1961, $y = 0.054e^{1.4275x}$
Figure 6.

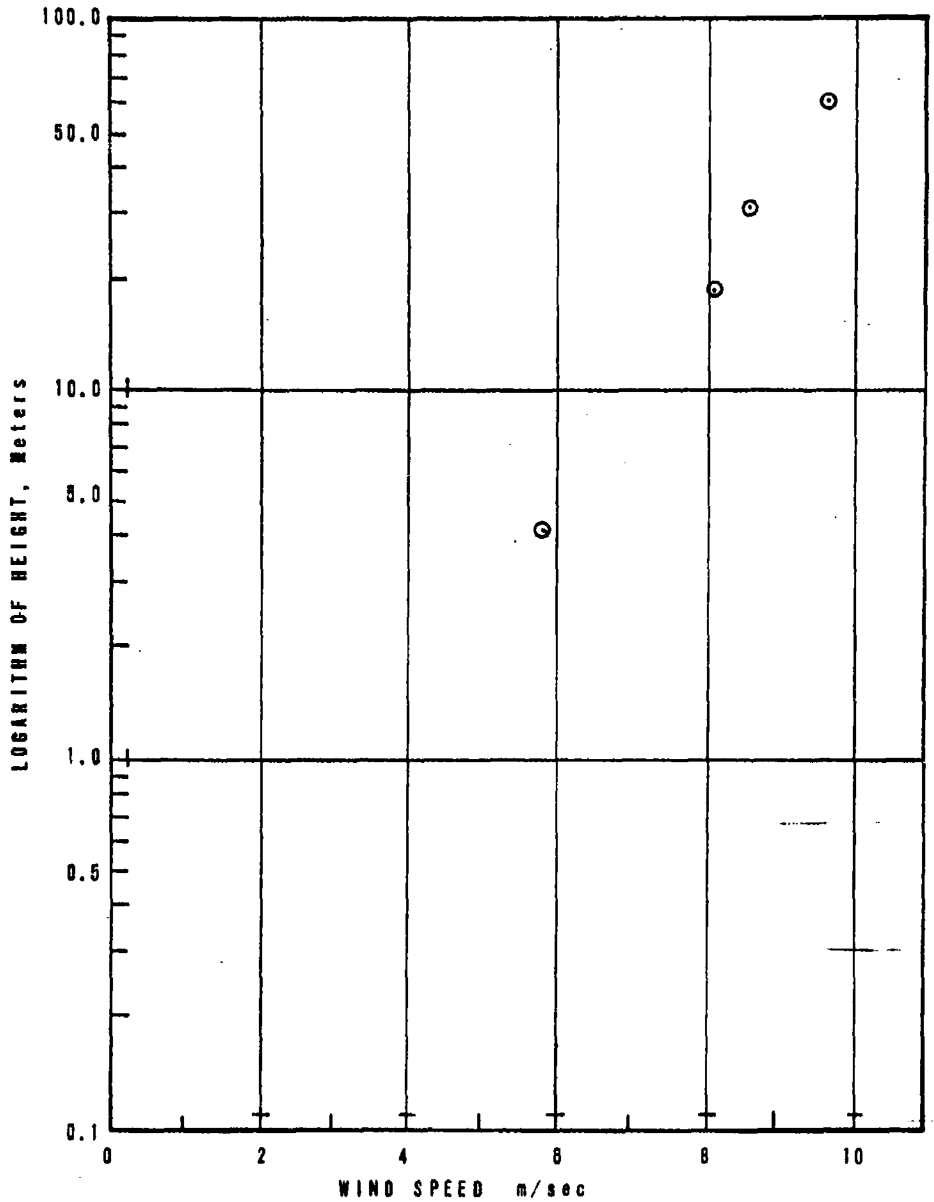


LOGARITHMIC WIND PROFILE FOR 1821 - 1830 MST
16 MARCH 1981, $y = 0.045e^{1.5726x}$
Figure 7

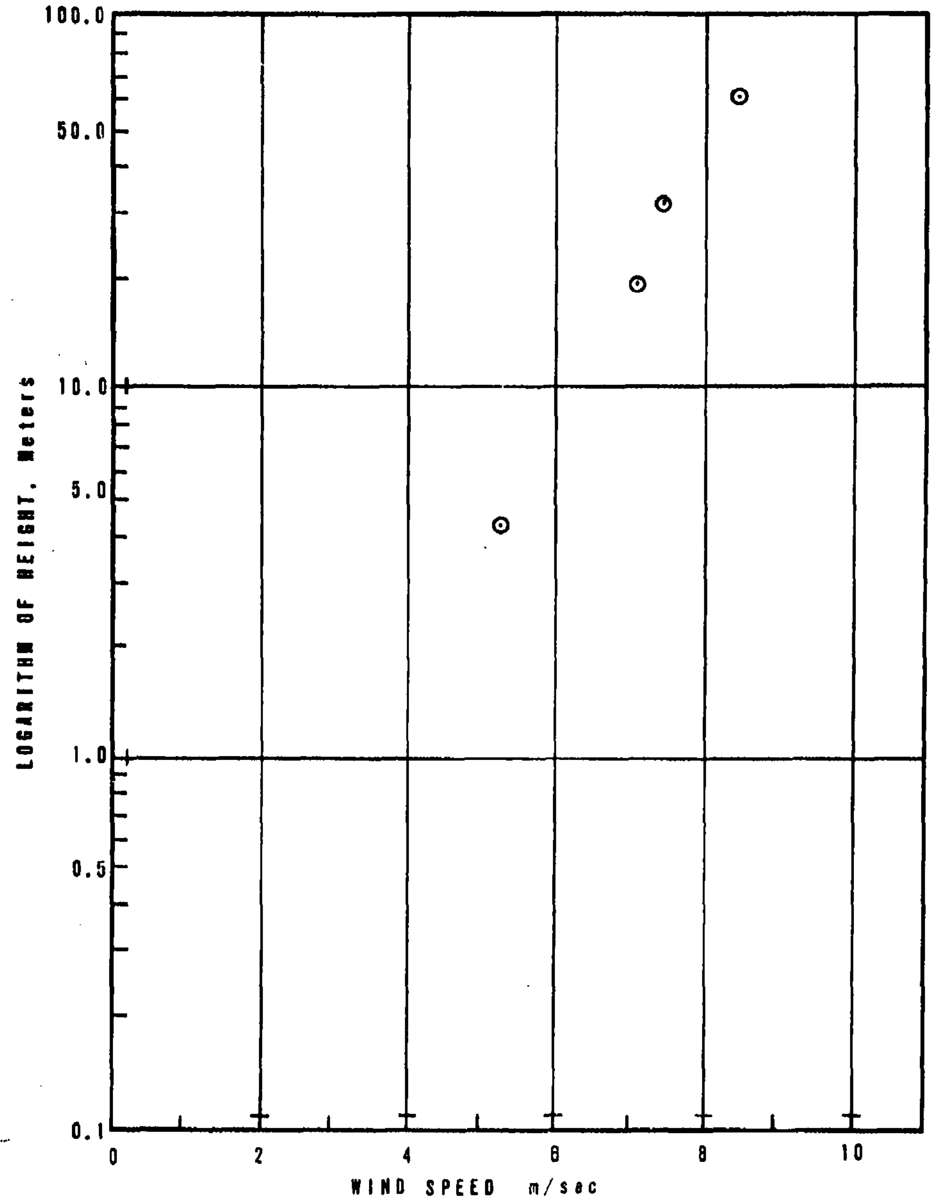


LOGARITHMIC WIND PROFILE FOR 1831 - 1840 MST
18 MARCH 1981, $y = 0.054e^{0.8395x}$

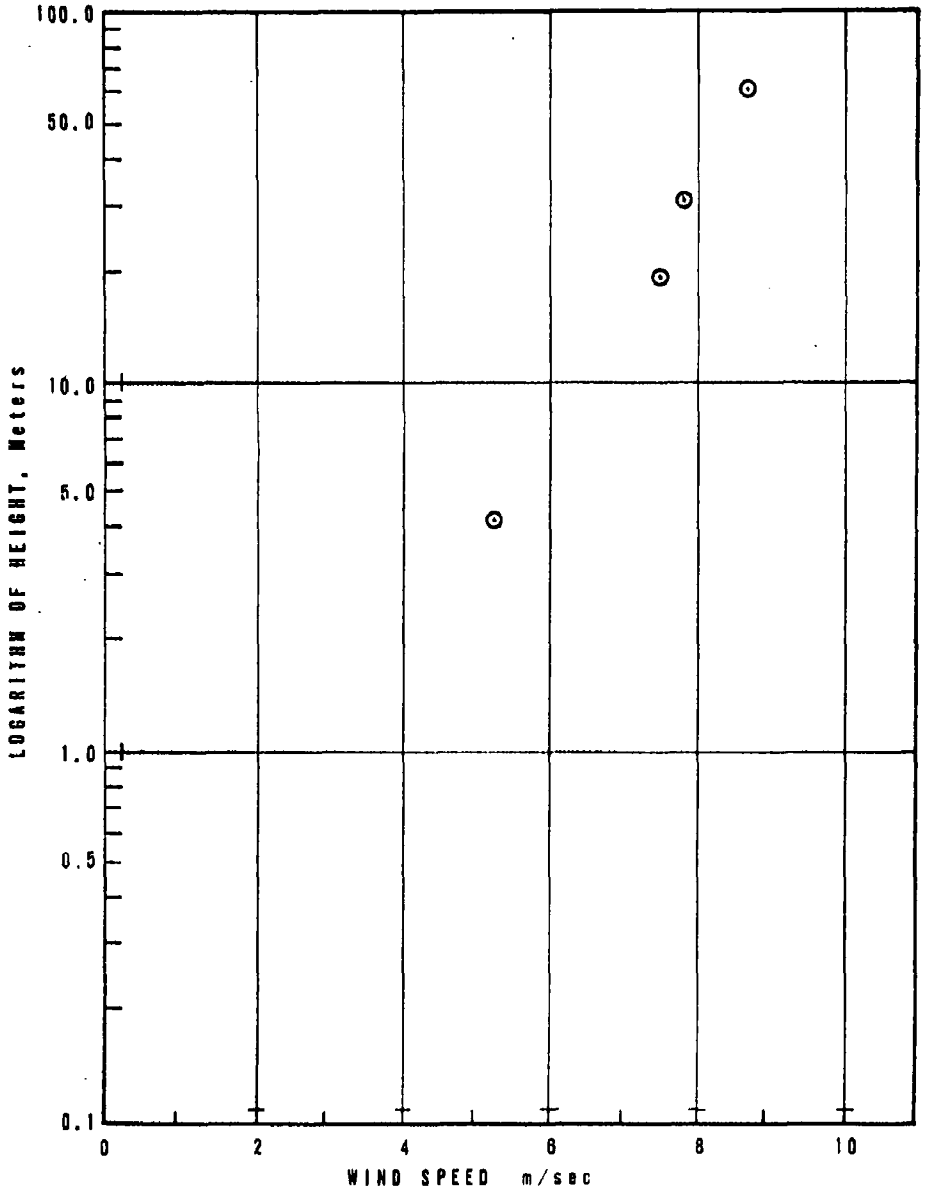
Figure 8



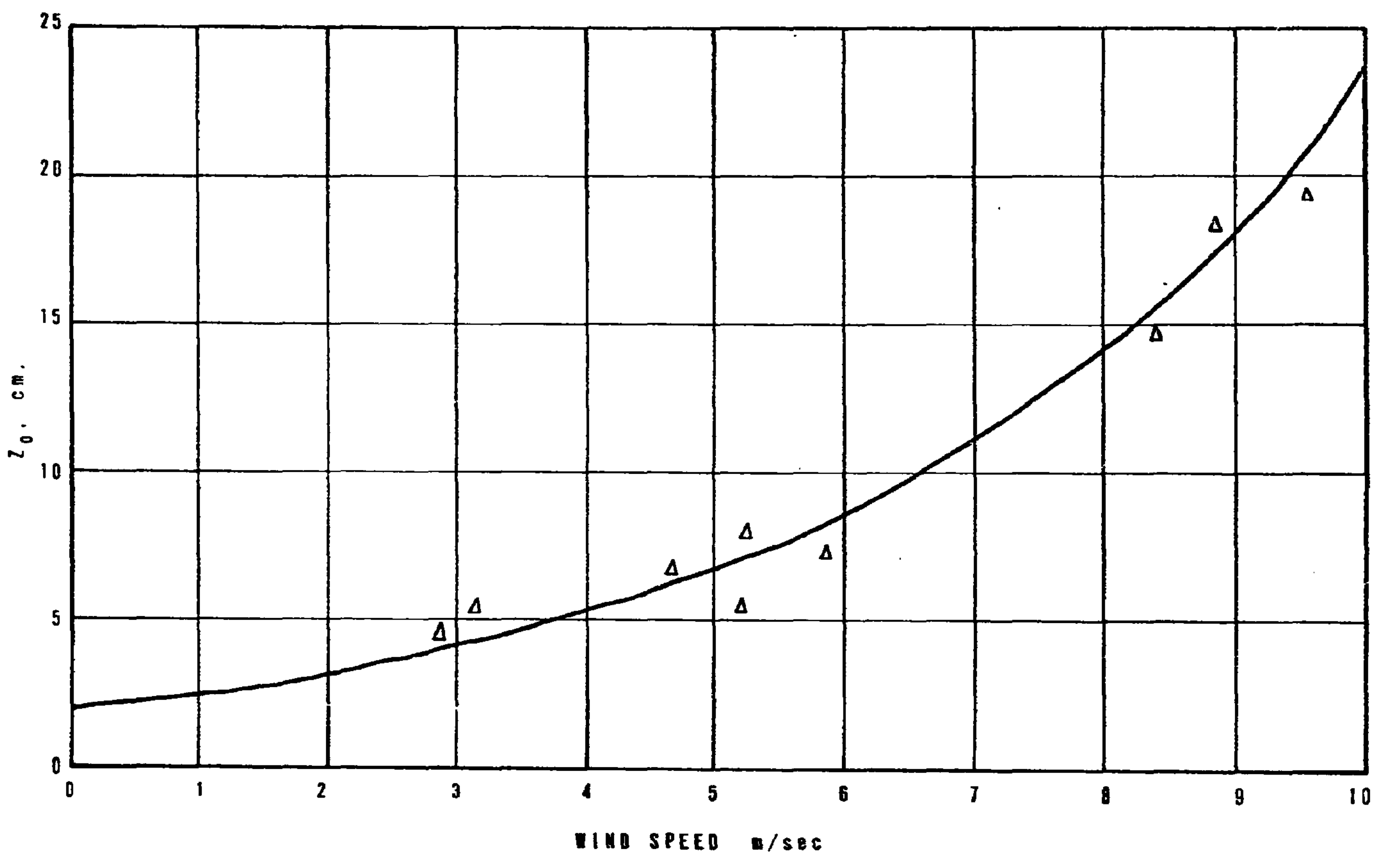
LOGARITHMIC WIND PROFILE 1831 - 1840 MST
16 MARCH 1961, $y = 0.071e^{0.7032x}$
Figure 9



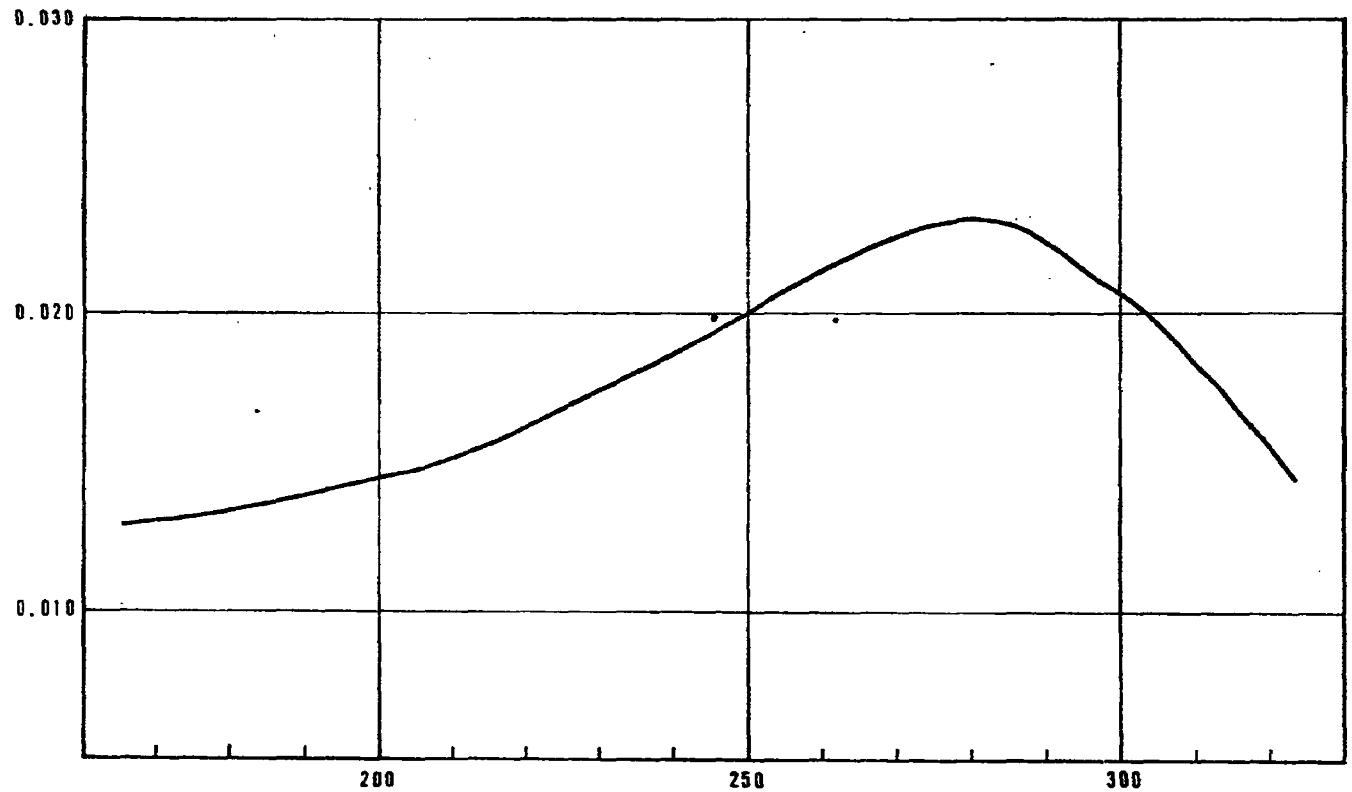
LOGARITHMIC WIND PROFILE 1841 - 1850 MST
16 MARCH 1961, $y = 0.054e^{0.8439x}$
Figure 10



LOGARITHMIC WIND PROFILE 1901 - 1910 MST
16 MARCH 1961, $6 = 0.0809e^{0.7555x}$
Figure 11



ROUGHNESS LENGTH, Z_0, vs WIND SPEED
Figure 12



WIND DIRECTION vs COEFFICIENT OF DRAG
Figure 13

All values of roughness length, friction velocity, drag coefficient, surface stress and eddy viscosity presented in Tables XI to XV appear to be reasonable and are in good agreement with those of other investigators, notably Deacon [6] and Sheppard [7] who found roughness lengths of 9 cm for thick grass up to 50 cm high, while drag coefficients for thick grass, assuming the Rossby [3] profile, were found to be on the order of 0.032.

The Wind Profile: Since neither the logarithmic profile nor the power law is actually valid under diabatic conditions, few conclusions may be drawn concerning the observed wind profiles. It can be generally stated that the power law would provide the best fit for this particular sample of data, which is in agreement with Swanson and Hoidale [8].

Test for a Fully-Rough Surface: With the concept of fully-rough flow, the influence of viscosity is considered to be negligible. Nikuradse [9] has proposed tests for smooth and rough surfaces, which can be stated as

$$\text{Smooth Flow:} \quad \frac{u_* z_0}{\nu} < 0.13$$

$$\text{Fully-rough Flow:} \quad \frac{u_* z_0}{\nu} > 2.5$$

assuming that the relation $z_0 = \epsilon/30$ can be accepted.

The quantity $u_* z_0$ is known as the macro-viscosity and is denoted by N. Nikuradse's criteria can thus be stated

$$\text{Smooth Flow:} \quad N < 0.13\ \nu \approx 0.02\ \text{cm}^2\ \text{sec}^{-1}$$

$$\text{Rough Flow:} \quad N > 2.5\ \nu \approx 0.4\ \text{cm}^2\ \text{sec}^{-1}.$$

Values of N are presented in Tables XI through XV.

It is seen that all data meet the rough flow criteria and the hypothesis assumed is valid.

Turbulent Flow Indicators: Cramer [10] shows that the standard deviation of wind direction is a good indicator of stability and, of course, turbulent intensity. Cramer's estimates are presented in Table XVI.

TABLE XVI

ESTIMATED RANGE IN STANDARD DEVIATION OF AZIMUTH WIND DIRECTION, σ_A, NEAR GROUND LEVEL FOR VARIOUS STABILITY STRATIFICATIONS

Stability Stratification	Smooth Site	Rough Site
Extremely stable	2- 4	2- 6
Moderately stable	4- 6	7-15
Near Neutral	6- 8	10-15
Moderately unstable	10-15	15-20
Extremely unstable	20-25	25-30

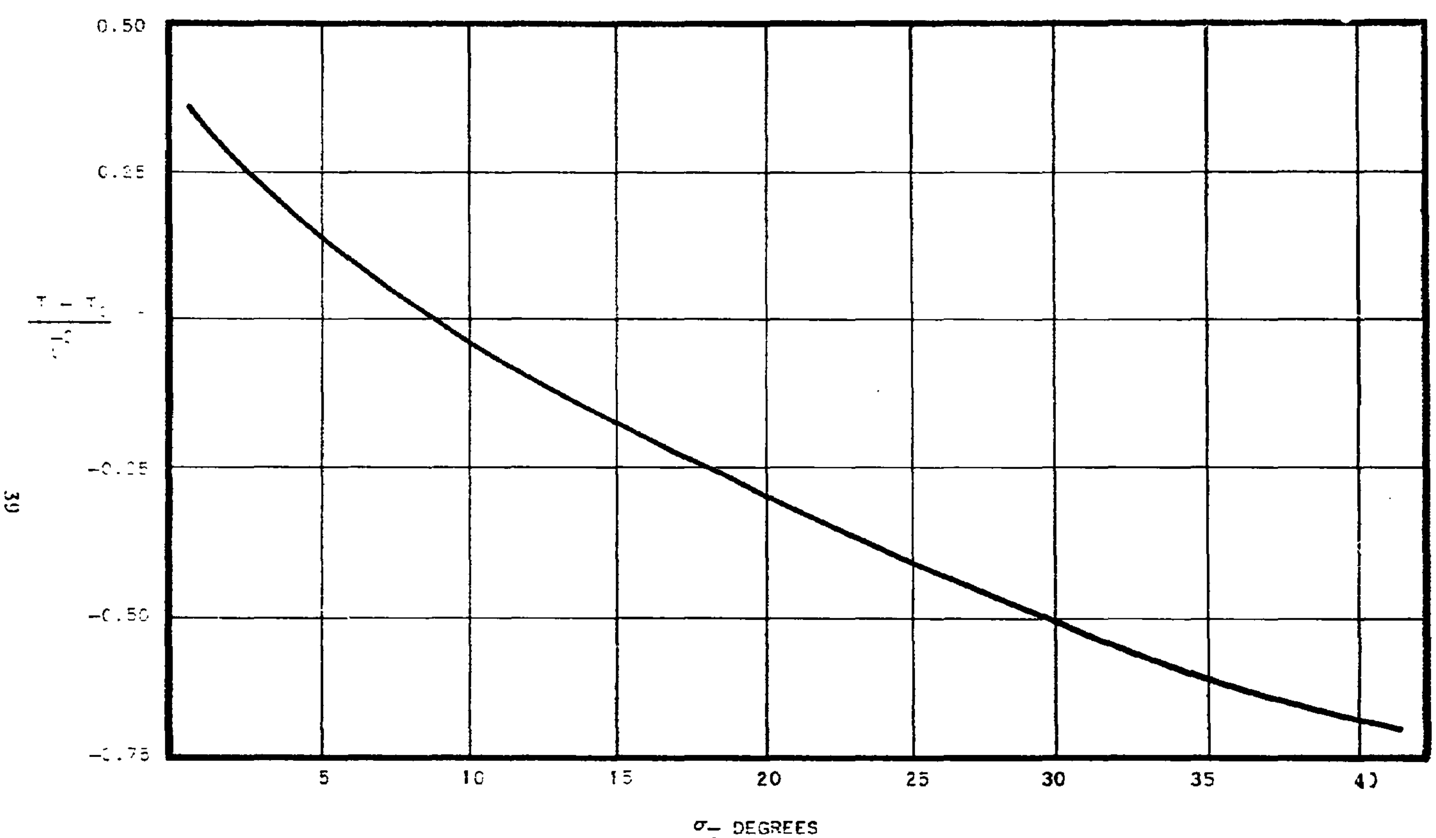
It is clear from Tables I to X and Figure 14 that the data agree well with Cramer's hypothesis. This is reflected by the gustiness ratio or intensity of turbulence

$$I = \frac{\sigma_{\bar{u}}}{\bar{u}}$$

where I is the gustiness ratio and σ_u is the standard deviation about the mean wind speed $\bar{u}$. Figure 14 is a plot of the standard deviation of direction vs stability. The stability ratio represents the ratio of temperature difference in degrees Celsius between 4.3 or 4.6 meters and 25.6 or 31.7 meters to the square of the mean wind speed at 19.3 or 19.5 meters, depending upon the data sample used.

Another indicator of turbulent motion in the boundary layer is an apparent inverse relationship between the variance of wind direction and the eddy viscosity. It appears that as the variance increases, the eddy viscosity decreases, indicating a breakdown of the viscous stresses with increased mixing.

While boundary conditions are dependent upon wind speed and are necessary for establishing the characteristics of turbulence for an area, it is obvious that the variance of wind direction is the determining factor in turbulent intensities and the propagation of turbulent motion downstream. Blackadar, Panofsky, et al. [11] show from Taylor's Hypothesis that Lagrangian and Eulerian standard deviations of azimuth are approximately equal during daytime, and that measurements at a fixed site are valid some distance downstream. Thus, Taylor's Hypothesis can be used to evaluate the behavior of the wind after it has passed a fixed point.



STABILITY RATIO $T - T_0/\bar{U}^2$ vs. STANDARD DEVIATION OF DIRECTION

FIGURE 14.

CONCLUSIONS

Turbulent characteristics of the atmospheric boundary layer in the vicinity of the U. S. Army Electronics Research and Development Activity Meteorological Research Tower are comparable to those observed at other locations. It can be concluded that the roughness length increases with increasing wind speed and varies with wind direction. This is attributed to changes in the fetch and the height of the roughness elements from different exposures due to wind direction shifts. The coefficient of drag of the surface varies with wind direction, exhibiting the same characteristics as the roughness length with relation to the fetch and roughness elements.

The standard deviation of wind direction was found to vary with the lapse rate while the eddy viscosity appears to be inversely proportional to all standard deviation of direction. All boundary conditions were found to be dependent upon wind speed and to some degree dependent on wind direction. The standard deviation of wind direction was determined to be a good indicator of turbulence.

LIST OF SYMBOLS

A	Wind Direction, Degrees
$\bar{A}$	Mean Wind Direction, Degrees
C_D	Coefficient of Drag
I	Gustiness Ratio
K_M	Eddy Viscosity
N	Macro Viscosity
P	Ambient Pressure
T	Temperature, Degrees Celsius
k	Karman's Constant
p	Wind Profile Index
u	Horizontal Wind Speed
u'	Instantaneous Horizontal Velocity
$\bar{u}$	Mean Wind Speed
u_*	Friction Velocity
w	Vertical Velocity
w'	Instantaneous Vertical Velocity
z	Height
z_0	Roughness Length
ε	Roughness Element
ρ	Density
τ	Shearing Stress
τ_0	Surface Shearing Stress
ν	Kinematic Viscosity

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Turbulent characteristics of the first 62 meters of the atmosphere in the vicinity of the U. S. Army Electronics Research and Development Activity Meteorological Research Tower are established for neutral conditions. The assumption was made that the roughness length is a constant, but dependent upon the wind direction, fetch, and the height of the roughness elements.

Data are presented for five recording periods during the late winter and early spring of 1958 and 1961. Computations of the basic wind profile and turbulence parameters are presented in tabular form.

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